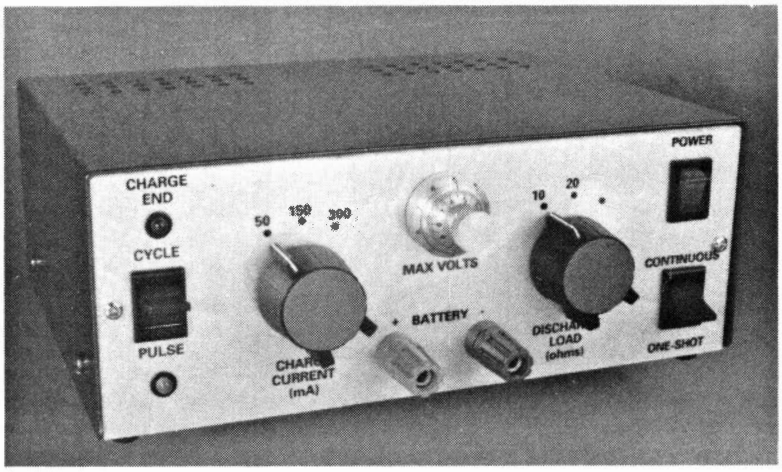
NiCad Recycler

Many users of NiCad batteries don't get the most out of this useful power source and a large number of cells falter and are discarded long before their expected life of 1000 charges. Peter A. Lovelock describes a very useful NiCad recycler that can restore failed cells and prolong their active lives



Why do NiCads fail?

Chief causes for premature failure are:

1: Frequent shallow discharge before recharging resulting in 'memory phenomena' - apparent loss of Ampere-hour capacity.

2: Charging to less than 1.4V per cell (not replacing 30% more energy than discharged) also effects memory.

3: Shorted cells. The shorted condition is caused by chemical 'whiskers' growing inside discharged NiCads. Cells with this fault condition will, when tested, measure zero voltage and zero resistance across the terminals and will not accept a charge.

4: Reversed cell polarity. This occurs when a cell in a series string becomes fully discharged and is then reverse-charged by the current flow from the other, healthier cells.

Fortunately, as has been proved, these defects are usually curable with proper techniques and most NiCads can be restored to full health. However, it should be realised that 'dryout' caused by internal seals rupturing from overheating, with the resultant loss of fluid, is incurable. This fatal condition can be recognised by the presence of small crystals deposited around the cell terminals.

The NiCad Recycler was designed to overcome many everday problems for the NiCad user and includes in one unit, all the facilities needed for curing, maintaining and prolonging the active lives of NiCad cells. It has also been designed with options for individual constructors. These features are :

1: One-shot Charge Mode. This is a programmable charge rate and has shut-off voltages suitable for one to ten cells (1.4 to 14V).

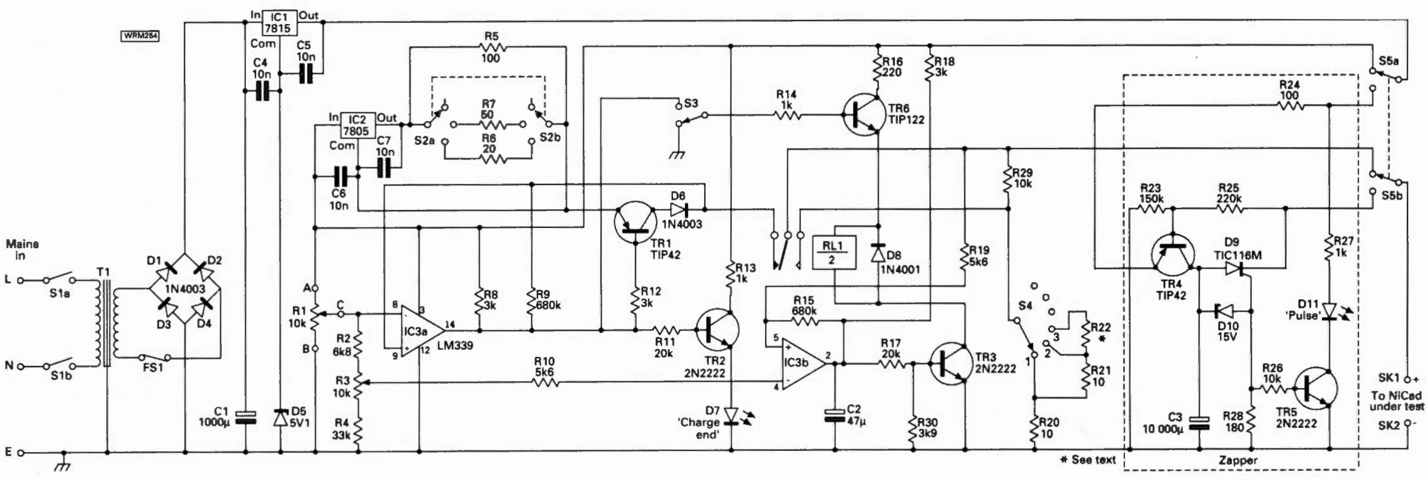
2: Continuous Cycle Mode. When full voltage (1.4V per cell) is reached, the battery is switched to a discharge load. When deep discharge is reached (1.0V per cell), the battery is switched back to charge. The battery will be cycled between charge and discharge over its full capacity range. Recycling can be done once, or periodically, to keep batteries healthy or as many times as needed to eliminate any memory condition.

3: Short 'Zapper'. This important and versatile facility on the unit applies high current pulses to shorted cells to burn out internal chemical 'whiskers' and /or repolarise reverse-charged cells.

How It Works

Now it's time to look at the circuit, Fig. 1, and see how it works. In my particular design, constant current charging is used, so as to avoid the initial high current and heating that can occur when the recharging of deeply-discharged cells is attempted. Overheating on recharging can be a common result of the constant voltage method and this problem is avoided in this design The circuit design, shown in Fig. 1, has evolved from a well-proven method

Fig. 1



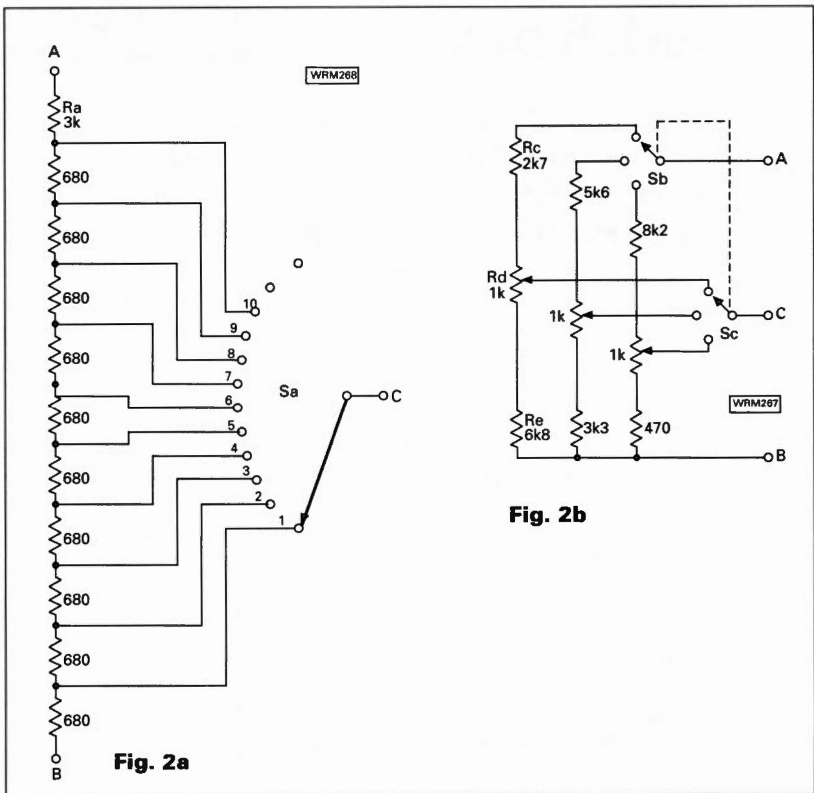


Fig. 2a

Fig. 2b

Fig. 2a & b: Two alternative methods of generating the reference voltage to pin 8 of the comparator IC3a

based on the familiar constant current charger using the 7805 regulator. This device is an ideal starting point for our purposes and has a current control resistor between the output and reference pins, the value of which sets the constant current rate. This resistor's value is determined by the simple equation;

$R=5 + I$ where I = required charge rate in amps.
e.g. for 50mA charge, $R = 5 \div 0.05 = 100\Omega$.
When using the versatile 7805 device in this way, the designer has much of the work done for him, although it must be borne in mind that the supply voltage to the 7805 must be at least 5V more than the highest charge voltage required.

For the chosen charger design to work effeciently, it must be able to restore 30% more energy than has been discharged by the cell. While under charge, each cell voltage must increase, to 1.4V and when a 10 cell battery pack is connected to be recharged, the maximum charge voltage will have to be 14V. So, with all these considerations borne in mind, the designer must appreciate that the the minimum supply voltage to the 7805 input is therefore: 10 x 1.4 + 5V = 19V. However, to err on the safe side we should aim for it to be between 20 and 25V d.c.

The final design, in Fig. 1 has evolved after much testing and evaluation. As previously mentioned, the heart of the unit is based on the 7805 current regulator and this is fed with a regulated +20V d.c. supply by a 7815 voltage regulator with a 5.1V Zener diode ground reference. The supply also powers the associated control circuits. In the circuit in Fig. 1, only three control resistors are shown for obtaining the necessary 50, 150 or 300mA charge rates. However, any number of resistors may be selected by appropriate switching to provide the desired range of charge rates up to the 1A maximum of the regulators. For reliability in operation, care must be taken when considering power dissipation of the resistors. It's not a difficult task and the wattage ratings of the resistors can be calculated easily by multiplying voltage times current (V x I); thus the 100Ω resistor for 50mA = 0.25W (5 x 0.05). Bearing in mind the reliability factor, it makes common sense to up-rate these resistors to 1W types, especially when the unit will be in use for very many hours at a time.

I used a two-pole multiway switch to select the three current control resistors which are connected to the output of IC2. As can be seen in Fig 1, a 100Ω resistor (calculated to pass only 50mA) is in circuit at all times. The 100Ω resistor is shunted either by 50Ω (= 33Ω for 150mA) or 20Ω (= 16.6Ω for 300mA) resistors. These shunt resistors dissipate about 1.5W and to err on the generous side I used 2.5W wirewound resistors.

In the charge/discharge control circuit two sections of an LM339 quad comparator (IC3a and IC3b) sense and control the maximum charge and deep discharge voltage limits as follows:

Continuous or One-shot mode is selected by S3 (shown in One-shot mode) and R1 sets a reference voltage on the inverting input to IC3a, equal to to 1.4V x number of cells. The non-inverting input of IC3a monitors the charge output voltage across the battery under charge. When the charge voltage rises above the reference voltage the output of IC3a goes high, biasing off TR1 charge current and causes TR2 to illuminate the 'end of charge' l.e.d. as well as applying power to the top of relay RL1 (S3 in Continuous charge position).

Hysterisis is applied to IC3a by the 680kΩ resistor between the output and non-inverting input pins, so that when the uncharged battery terminal voltage drops approx 0.2V, IC3a output will again go low, TR1 turns on the charge current and the l.e.d. goes out. This on-off cycle repeats as the terminal voltage rises or falls relative to the reference voltage with the charge current being pulsed (rather than tapering down) and pulsation decreasing as the battery 'tops off'. The pulsating end charge is very effective in bringing the battery to the full charge of 1.4V per cell without forcing the cells into overcharge or heating. After several hours on pulsating charge, no discernible heating has been noted. With the Mode switch (S3) set on Continuous cycle, the l.e.d. D7 illuminates to signal that the charge cycle is complete.

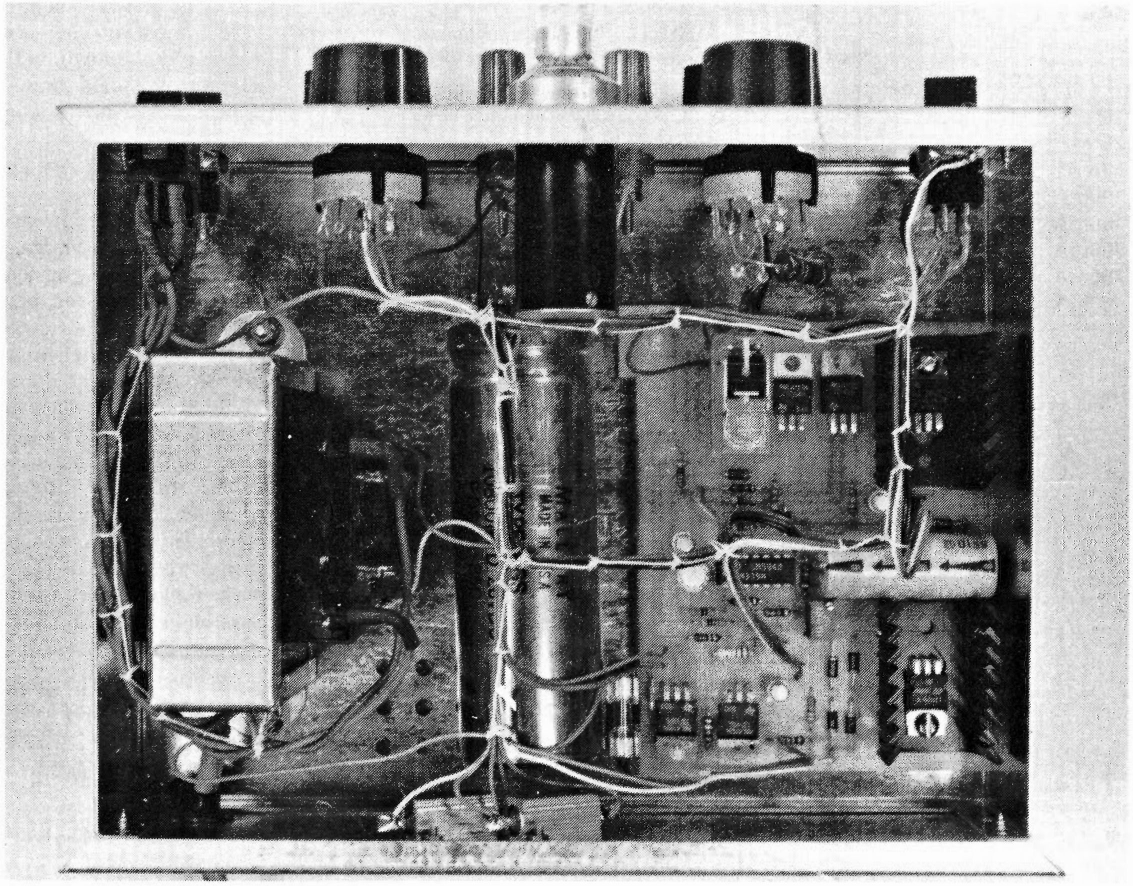
Recycle Mode

The first time that the battery terminal voltage rises above the charge reference voltage, IC3b output goes high, TR3 conducts and energises relay RL1 which switches the battery across a discharge load resistor shown as a switched (S4) value of resistance. Discharge continues until battery voltage drops below the deep discharge reference level, the level of which is set by R3 to the inverting input of IC3b (the reference level is equal to 1.0V x number of cells), IC3b output is then high, keeping TR3 in conduction. When the cell or battery voltage drops below the R3 reference, IC3b output goes low and de-energises the relay which switches the battery back over to the charging circuit. Interruption of the relay current causes the battery to be put back onto recharge.

The potentiometer R3, with external resistors, sets the discharge voltage limit to approximately 70% of the full-charge limit (1.0V x number of cells). Since the lower reference network is supplied from the wiper of R1, it will always track R1. Resistor R3 needs only to be adjusted once.

Setting the charge voltage is very dependent on the accuracy of R1, which has to be calibrated for

each combination of cells (i.e. 1, 2, 3 and up to 10 cells). A ten-turn potentiometer with a dial is recommended for ease of resetting. Suitable units may be obtained from one of the mail order suppliers. If this source of supply fails there are options for providing accurate reference voltages, and two methods are shown in Figs. 2a and 2b.



Internal view of the NiCad Recycler

Shorted Cell Zapper

Burning out internal NiCad shorts by discharging a large (10000μF) capacitor through the offending cell is not a new idea. While effective, it was found that many discharges were required to fully clear the shorts and the process was cumbersome using a clip-lead hook-up. Another method, connecting up one or more good cells across the shorted cell works well, but could result in excess heating and damage if the heavy current is sustained for too long.

The automatic zapper circuit in Fig. 1, shown within the area enclosed by the broken lines on the main circuit diagram, is simplicity itself. The zapper applies repeated short duration high current pulses to a shorted cell, which positively clears whisker shorts without potential damage to the cell under treatment. The zapper is included as part of the complete circuit, but may be built as a stand-alone unit permitting charge conditioning and short zapping of different cells at the same time. Only one cell at a time should be zapped however, as the effectiveness of the energy pulse is very much reduced when more than one cell is treated in this fashion.

How The Zapper Works

When the zapper section (Pulse) of the unit is selected, the regulated 20V d.c. charges the 10 000μF capacitor through TR4, which is in conduction. When the voltage across the capacitor reaches 15V, the Zener diode (D10) conducts, triggering the s.c.r., D9, which discharges the capacitor through the battery in a short burst of high energy.

Negative feedback to the base of TR4 through the 220kΩ resistor, causes the transistor to shut down the charging current until the capacitor is fully discharged and the s.c.r. becomes non-conducting. When TR4 conducts, the capacitor is again charged and the entire cycle is repeated continuously, applying short bursts of high current through the shorted cell.

The l.e.d, D11, across the output, which indicates the condition of the cell, is normally off since the battery is a direct short, but it flashes each time a pulse is applied. When the shorted battery is cleared, the l.e.d. lights continuously indicating that battery condition is good. To make sure it stays so, it is recommended that the battery be left on the zapper for 10 to 30 minutes after the l.e.d. comes on. (Depending on how long it initially takes to clear the short in the cell). This ensures that whisker shorts are thoroughly cleared before putting the cell back into service. Right after removal from the zapper, the cell may display a voltage of 1.25V BUT SHOULD IMMEDIATELY BE PUT ON A LOW CHARGE UNTIL A FULL 1.4V IS MEASURED UNDER CHARGE. This ensures that whisker shorts will not grow back within a few days, but will be cleared by the cell's full charge.

In addition to clearing shorts, the zapper will repolarise cells that have become reverse polarised. However, not all sick NiCads can be rejuvenated. Some are just worn out from use. Cells which have been subjected to severe overheating may have ruptured safety seals (a built-in protection to avoid explosion) and have leaked electrolytic fluid. This can be detected by looking at the insulator ring between the + terminal and the case. If this area contains small crystals, the cell should be discarded.

An Economic Variation

As already mentioned, there is an alternative to the somewhat expensive ten-turn potentiometer, R1 in the circuit diagram, Fig. 1. Two alternative methods of generating the reference voltage to pin 8 of the comparator IC3a are shown in Fig. 2a and Fig. 2b. The first alternative, shown in Fig. 2a, is a resistor chain consisting of ten 680Ω resistors and a 3kΩ resistor to make up the total resistance to

TABLE 1

Current	Other resistor
10mA	none
25mA	330Ω
50mA	120Ω
100mA	56Ω
150mA	36Ω
200mA	27Ω
250mA	22Ω
450mA	12Ω

around 10kΩ. The total current flowing in this chain is a nominal 2.05mA, this gives 1.395V across each of the 680Ω resistors. This figure is close enough to the required charge end point voltage for NiCad cells. The switch method allows the number of cells under charge to be chosen very quickly, but lacks the versatility of the multi-turn potentiometer. The switch, Sa, is a single-pole, 12-way switch with only ten positions utilised to select the appropriate setting for the number of cells to be charged.

Should there be no requirement to charge many differing battery types, then the variation shown in Fig. 2b, could also replace R1 in the main circuit diagram (Fig.1). Again, it is a resistor chain of around 10kΩ total resistance with a take-off voltage as required for the number of cells under charge. The configuration as shown, with a chain consisting of Rc, Rd and Re is that calculated to allow the end point charge limit for a 10 cell battery pack (nominal 14V) to be set. The actual value of voltage should be able to be set over the range of 13V to 15V. This voltage would be suitable for battery packs for the FT-290/690 series or the TR-2300 hand-held portable transceivers. The middle combination of resistors gives a range suitable for battery packs with a nominal voltage of 7.2V, which covers most of the newer palm-sized 'handy' transceivers. Shown on the right is a combination which is adequate to cover the charging of 1or 2 cells in series with the adjustment covering 1-3V.

Suiting Your Needs

If the constant current values are unsuitable for the cells under charge, that problem is easily overcome and may be changed by alteration of the resistor combination between the 'out' and the 'common' terminal of constant current generator IC2. This i.c. tries to maintain a constant 5V between these pins.

So, if for example, a 10mA setting were required for charging 9V (PP3 type) rechargable batteries, then you should change R5 to 510Ω, and alter the values of R6 and 7 to add the additional values. Although only three positions are shown, the switch recommended is a two-pole 6-way item, and so six current ranges could be included in the finished project and a table, Table 1, is provided, showing possible values of resistors, assuming a lowest charging current range of 10mA.

In Part 2 we will deal with the construction and the setting-up of the NiCad Recycler. The p.c.b. will also be included in Part 2.

HOW MUCH ?
£ 40.00
HOW DIFFICULT
Intermediate

Shopping List

Resistors

5% 0.5W Carbon film

100Ω	2	R5,24
180Ω	1	R28
220Ω	1	R16
1kΩ	3	R13,14,27
3kΩ	3	R8,12,18
3.9kΩ	1	R30
5.6kΩ	2	R10,19
6.8kΩ	1	R2
10kΩ	2	R26,29
20kΩ	2	R11,17
33kΩ	1	R4
150kΩ	1	R23
220kΩ	1	R25
680kΩ	2	R9,15

1.5W Wirewound

20Ω	1	R6
50	1	R7

5% 15W Wirewound

10Ω	2	R20,21

10-turn variable

10kΩ	1	R1

22-turn Cermet (vertical mount)

10kΩ	1	R3

Note: Values of R22 will vary according to the discharge load and voltage.

Capacitors

Monolithic ceramic

10nF	4	C4-7

Electrolytic axial lead

1000µF	1	C1

Electrolytic radial lead

47µF	1	C2

Electrolytic Computer Quality

10000µF	1	C3

This capacitor type normally has screw terminals and they are capable of very high ripple current. The efficiency of the zapper unit is very much dependent on this capacitor and it is recommended that the normal electrolytic capacitor be avoided

Semiconductors

Diodes

BZX61C5V1	1	D5 (1.3W Zener)
BZX61C15	1	D10 (1.3W Zener)
TIC116M	1	D9
1N4001	1	D8
1N4003	5	D1-4, 6
l.e.d.	1	D7 (Electromail 587-080)
l.e.d.	1	D11

Integrated Circuits

LM339	1	IC3
LM7805	1	IC2
LM7815	1	IC1

Transistors

TIP42	2	TR1,4
TIP122	1	TR6
2N2222	3	TR2,3,5

Miscellaneous

Relay 12V double-pole change-over (Electromail part no. 351-572), Transformer 24V 1A, fuse holder and fuse (1.5A), box to hold project was a Maplin type 2108, two off 2-pole 6-way switch, two pole change over switch, single pole change over switches, on/off switch plus knobs to suit, sockets for the battery connections, p.c.b. and interconnecting wire.

Electromail.
PO Box 33,
Corby,
Northants NN17 9EL.

NiCad Recycler Part 2

In this second part of the NiCad Recycler, Peter A. Lovelock looks at building and setting the unit up for everyday use

The unit is built on a p.c.b. that holds most of the main components. The case that houses the NiCad Recycler should be provided with adequate ventilation holes to ensure a good air-flow.

By allowing a good flow of air over the transformer and other components you should get a long and trouble-free life from the Recycler. The importance of this factor should not be overlooked, especially when you consider the long cycle times needed for some larger capacity batteries.

A suitable enclosure for the project is a steel case, such as the Maplin type 2108. This case provides a sturdy enclosure and has the advantages that the front and back panels are detachable. Also more than adequate ventilation holes are provided in the design.

Layout

With the recommended lay-out, the mains transformer and the p.c.b. are arranged so that there are gaps between them. This will aid cooling and will also allow the large computer-type electrolytic capacitor for the 'Zapper' facility to be suitably placed. The suggested front panel layout is shown in Fig. 2.1. I recommend that you stick to this layout, as it seems to work well in practice. Power for the Recyler is provided from a 24V secondary transformer with a 1A rating. Again, in practice this rating has proved to be perfectly acceptable. The transformer fitted into the *PW* prototype only became barely warm to the touch after many hours of use.

In the prototype this electrolytic capacitor was held in place by double-sided adhesive tape. A spring-clip type of holder is perfectly acceptable if you don't mind the extra drilling required for the necessary fixing bolts.

Heat Dissipation

The case has ventilation holes provided in the bottom plate and a further series along the top cover. These inbuilt holes should be more than adequate and no further holes will be needed for the unit in normal use.

Heat sinks for IC1 and IC2 are essential for reliable operation. For the most efficient transfer of heat, silicone grease may be applied between each i.c. and its heat sink. The rear panel provides an excellent heat sink for the only other high-dissipation components. These are 15W wire-wound 10Ω resistors R20 and R21. Neither of these resistors require heat-sinking compound as they bolt directly onto the rear panel, which provides a large heat dissipating area.

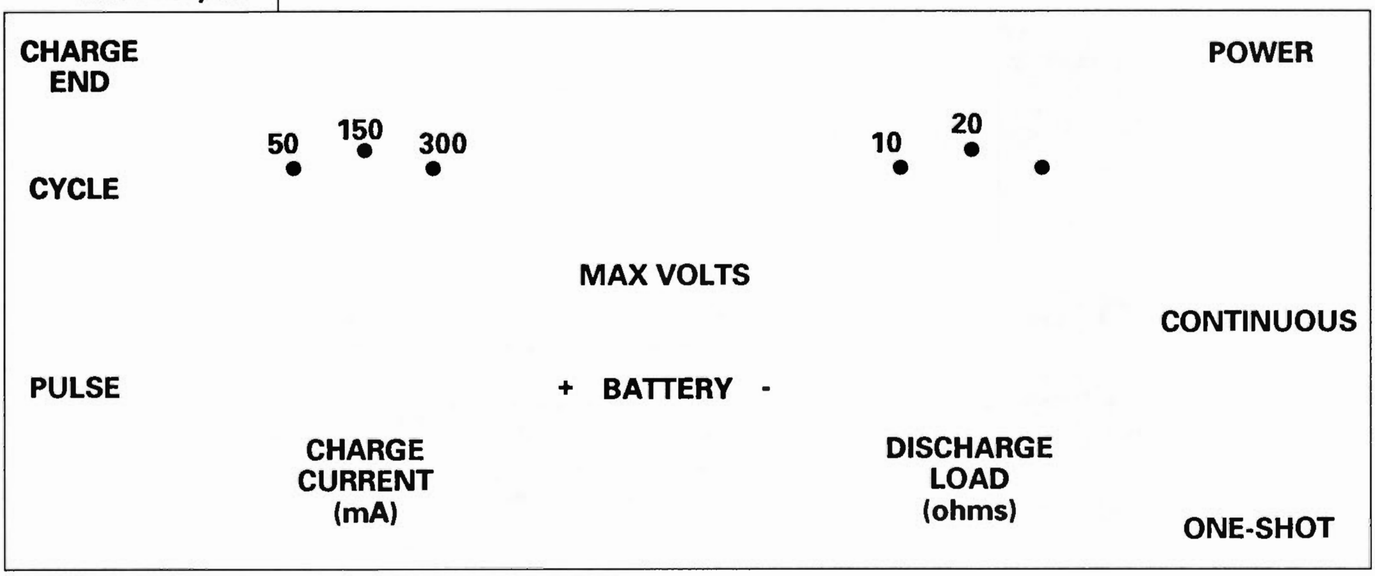
The p.c.b., track and component overlay are shown in Fig. 2.2. The heaviest gauge wire possible should be used for the of-board connections to C3+ and S5b. A short thick wire should also be connected from the negative of the capacitor C3, to socket SK2. High current pulses are carried in this area of the circuit and its efficiency depends on the lowest series resistance in circuit.

To build the unit, follow the layout shown, there's no special order of fitting components to the board. You should also examine the p.c.b. for solder-bridges and poor connections or wrong component placing.

Calibration and Adjustment

If everything is okay the Recycler will be ready for initial calibration. To calibrate the charge voltage limit, connect an accurate voltmeter (preferably a digital type) between the wiper of R1 and ground. Adjust R1 for each end charge voltages (while logging the potentiometer dial setting). Table 1 shows the ideal end charge voltage for one to ten cells. If using the switch option as outlined in the last part then check that

Fig. 2.1: The front panel layout of the NiCad Recycler



the correct voltages are as shown for the appropriate cell count (see Table 1).

To calibrate the deep discharge limit, set the charge maximum to 8.4V (6-cells). Connect the voltmeter to the wiper of R3 and ground. Adjust the level, using R3, to 6.0V (1V per cell). No further adjustment of R3 is required since it automatically tracks the setting of R1.

The discharge load resistor in the prototype is made up from two 10Ω 15W resistors (mounted on rear panel) that suits the requirements of recycling 12V transceiver battery packs. A 10-cell, 12.5V 500mAh pack discharges at 625mA in about an hour. However, a single 1.25V 500mAh size AA cell will discharge 62.5mA in about 8 hours. The extreme case,

Table 1. End charge voltage for battery packs

1.4V (1 cell)	2.8V (2 cells)	4.2V (3 cells)
5.6V (4 cells)	7.0V (5 cells)	
8.4V (6 cells)	9.8V (7 cells)	11.2V (8 cells)
12.6V (9 cells)	14.0V (10 cells)	

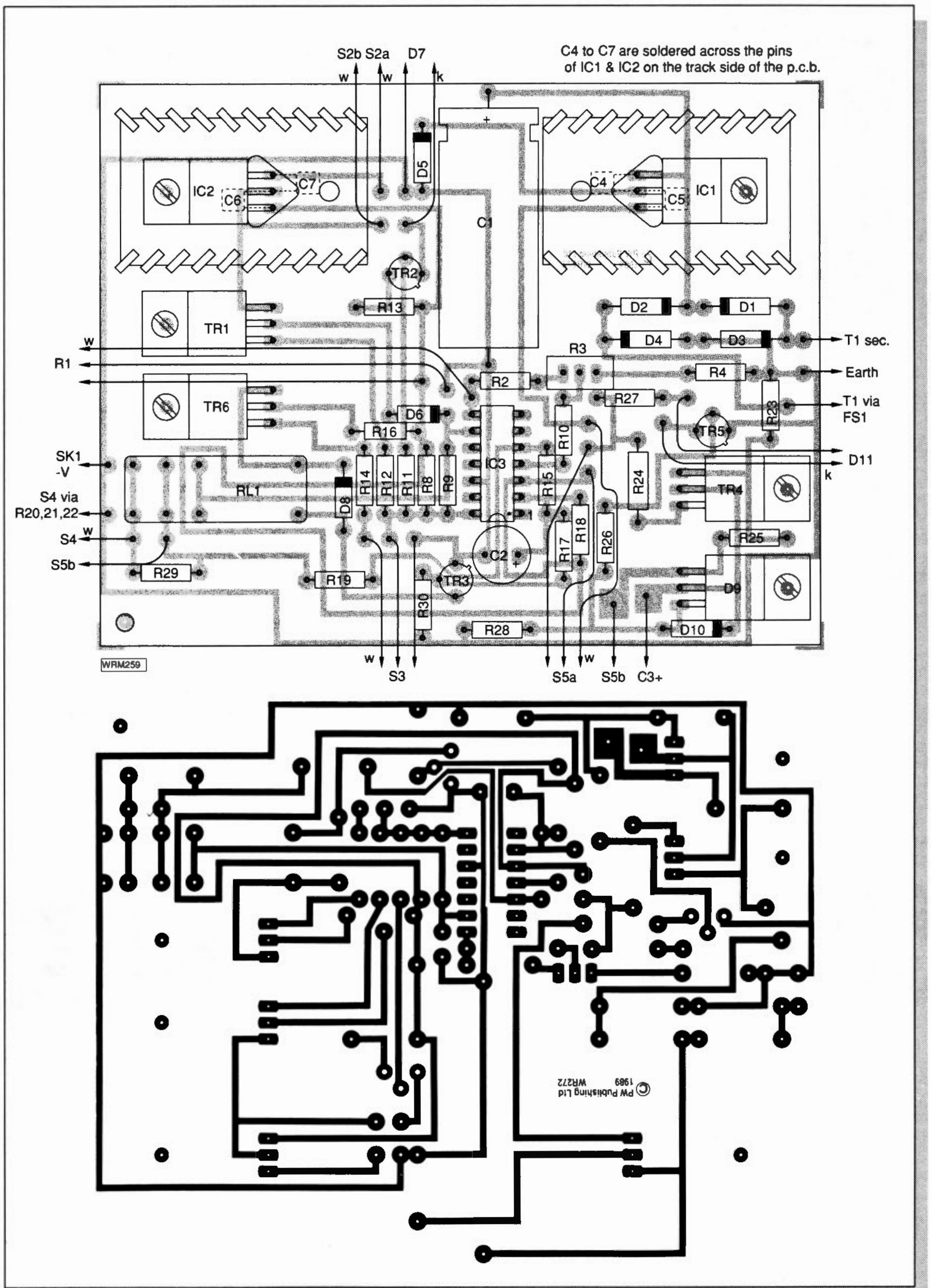
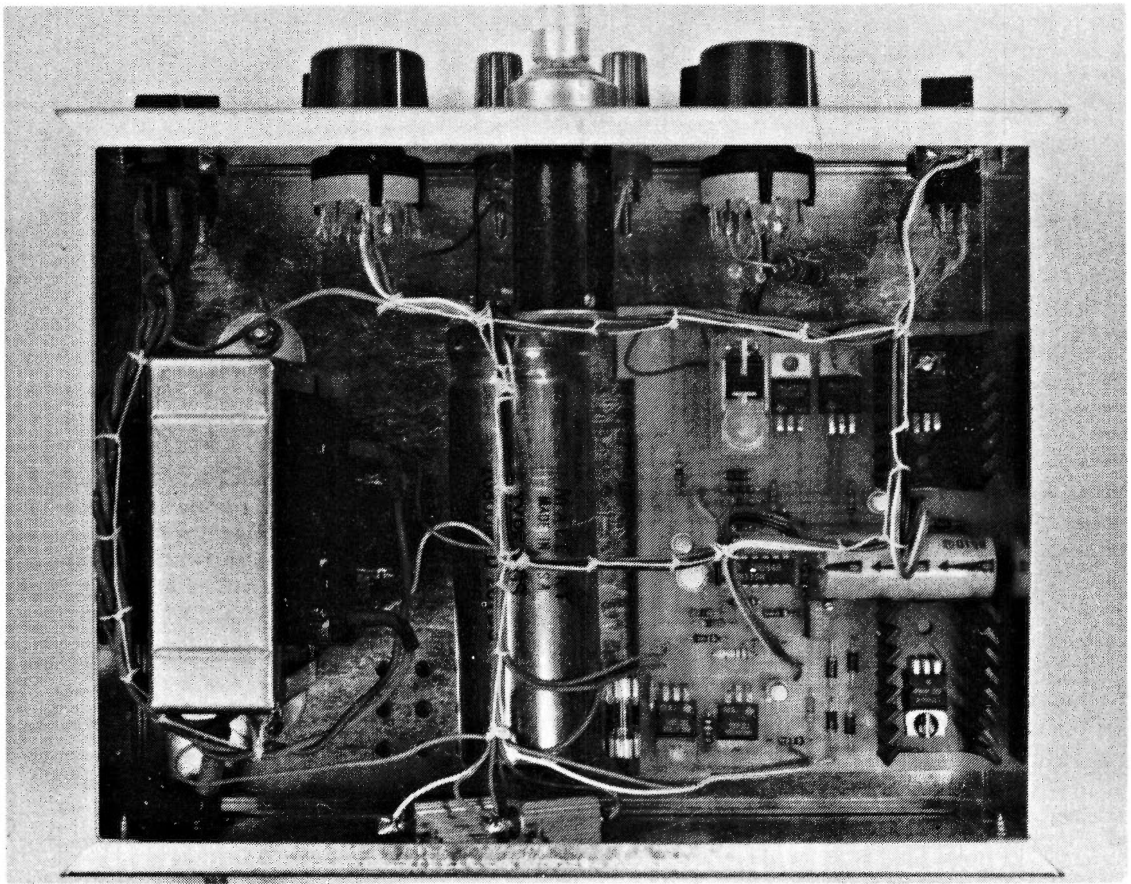


Fig. 2.2: Component overlay and track pattern for the project. The p.c.b. will be available from the *PW* services



The completed NiCad Recycler

a single 4000 mAh D cell will take 64 hours to discharge fully, which is time consuming for recycling.

If you expect to recycle high capacity cells, you will need to select appropriate loads for maximum permissible discharge rates to speed up the process. Maximum discharge current should not discharge a cell in under one hour. Load resistor values may be calculated using Ohm's law ($R = V \div I$) for the total voltage and maximum discharge current for each combination.

DO NOT FORGET that high levels of heat can be generated during discharge.

General

When first recycling a 'memorised' battery best results are obtained by using a low charge rate of one tenth of the ampere hour rate (e.g. 50mA for 500mAh AA cells). Remember that charge and discharge values may be altered to suit your requirements. Don't forget that low capacity battery packs should not be subjected to heavy discharge current. This could lead to a state of insufficient discharge and cause the cycling to be less effective than it might be.

Individual Cell Records

Many NiCad users will have a multiplicity of cells. In fact, it is very easy to lose track of each individual cell. How about keeping tags on them? One method is to give each cell a number and keep a record on each. You could then have a very useful record as to how individual cells have faired. More importantly perhaps, it may show if one brand of cell is proving to be more reliable than others. Together your NiCad Recycler and cell-log could save you a great deal of money and time!

PW